Overall challenges in age estimation – from bones to teeth

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Abstract

Different methodologies of age estimation using different human physical parameters have been assisting Forensic Science over the years. Limitations have also been acknowledged but there is a need to discuss about the overall challenges currently faced by experts from different backgrounds. The aim of this literature review was to gather scientific information of difficulties encountered in different parameters in the skeleton for age estimation. The conclusion is that a multidisciplinary approach is recommended for the legal age assessment due to the seriousness of the outcomes and finally, the experts should recognize the reality that chronological age will not always follow the maturity parameters of human development.

Keywords: age, estimation, forensic, odontology, methodologies

Introduction

Methodologies of age estimation are employed in living individuals for immigration control, assessment of age of criminal responsibility and employed in skeletal remains in order to estimate the age-at-death.[1] Age estimations in living can also be requested for appropriate school level placement, social benefits, employment and marriage.[2] In sport, age assessment may be necessary when participants claim to be younger than they are, a practice called age fraud.[3] Knowledge of chronological age is also important for regulation of growth achievement and nutritional wellbeing in children whose data collection are computed by community census.[4]

It is claimed that the complexity of human development is attenuated when different parameters of analysis are combined. Variations in physiological age is more well understood when the relationship between dental, skeletal and chronological age in children is established.[5] Unfortunately, the difficulty of assessment escalates at the same rate as the human growth and development progress to the maturity. Furthermore, the evaluation of single variables does not yield sufficient data for the accuracy required.[6]

More importantly, methods of age estimation must be peer-reviewed and presented to the scientific community with clear information about accuracy. Also, principles of medical ethics in cases of living individuals should be acknowledged.[7]

Literature Review

Age of Majority - The biological threshold of the legal ages of 16, 17, 18 and 21.

In criminal prosecutions, the age thresholds of relevance lies between 16 and 22 years in many countries.[8] Regrettably, age assessment is particularly difficult when the individuals are between their late teenage years and young adulthood. [9] An adolescent incorrectly assessed as an adult may be exposed to risk if placed within an adult environment.[10]

One of the most used indicators of child's health is the pattern of linear growth[11], through the use of charts. A simple interpretation of a charts demonstrates that whilst the child grows and develops, the curve is ascendant and approximately decelerates by the age of 16 and plateaus till the age of 18, where the maturation stage takes the main role. More precisely, girls reach a plateau after the age of 16, whereas boys have a linear trend from the age of 17 to 18.[12] The age range of 16-21yrs encompasses the phase which ceases the growth and starts the maturation, consequently, the analysis of correlations is likely to be more difficult.

Biological methods in use for evidence of age of majority.

All bones and body systems grow in synchrony from birth to complete development and their undergoing changes can be used to assess maturity. Age variation for every other developing and growing bone and body system is poorly documented. [13] Some scientists allege that different bones (or parts of) may grow independently[14] to some extent under the influence of localized agents.[15] It is paramount to point out that the documentation of data from different studies should diverse in samples of ethnic background, geographic location and be always peer-reviewed and compared in order to find possible

patterns and variations. A possible construction of population-specific tables would increase the accuracy of age assessments.[16]

The most widely used methods to estimate age include skeletal growth characteristics, epiphyseal fusion of bones and dental development.[17] Some study groups detail that age estimation consists of a physical examination which also records anthropometric data, signs of sexual maturation, an X-ray of the left hand and a dental examination. It is important to recognize that sexual maturity evaluation should not be used solely because of the large range of variation.[8]

Radiograph of the left hand is used to analyse the form and size of bone elements and the degree of epiphyseal ossification. The atlas method according to Greulich–Pyle (1930) is the most commonly used method[18] where different images of development stages of boys and girls (0 -18yrs) are consulted. Limitations of this method are: (a) concerning about the possible margin of error of which is ±6 months;[14] (b) subjects were Americans of Northern European ancestry and its application in other races is questioned;[19] (c) studies showed that method is more variable in females;[14] and finally, (d) changes in the carpals are not clear after the age of 14-16 years.[20] A study found that the mean age of attainment of a mature hand-wrist X-ray is under 18 years and most individuals are mature before the age of 18.[21]

This age range limitation (14-16yrs) could be compensate with a computerised tomography (CT) or radiological examination of the clavicles to establish whether the person concerned has attained the age of 21.[22] This assessment is recommended for individuals who are assumed to be at least 18 years old[23] as the sternal end of the clavicle continues to grow into the 20s. However, this method has also limitations because of: (a) radiation of internal organs involved; (b) great variation of complete closure between individuals (14.7-30yrs♀; 16.0-30yrs♂);[24] (c) technical problems such as risk of over-projection of bone (3 radiographs must be taken) and (d) absence of a patient's position standard. In short, if the epiphysis of the clavicle (= collarbone) is immature on the radiographs, the age of majority has been reached or there is a technical

deficiency; yet, finding the epiphysis is not an automatic proof of minority either, as the individual's personal anatomic development could be the reason.[25]

A research which combined the analysis of the distal tibial epiphysis and the calcaneum using magnetic resonance imaging (MRI) showed good results for age estimation in the threshold of 18 years old. Individuals were correctly evaluated: females aged 18 or more (97.7%) and males aged 18 or more (91.7%). Drawbacks of this research were (a) the possibility of errors in females because the epiphyses mature earlier than in males and also (b) the lack of information concerning the ethnicity of the subjects studied.[26]

Conforming to the same aim, analysis of the ossification of the epiphyses of the knee joint in antero-posterior radiographs were performed.[27] Good advantages of this anatomical area are: the low radiation doses, nonappearance of interposed anatomical structures and the assessment of 3 epiphyses at the same time (distal femur, proximal tibia and proximal fibula). Analysis of results showed high sensitivity (93.33%) and specificity (89.29%) for boys and high accuracy (85.86%) for girls. Authors directed attention to the limitations which involves (a) observer experience in interpreting radiographic films, (b) two-dimensional nature of radiographs and (c) the need of further studies with larger sample groups,[28] but those issues are also found when assessing other bone structures.

The trilogy I: skeletal, dental and chronological age.

The comparison of skeleton, teeth and chronological age is a complex subject to investigate because the rhythm of human growth. It might not occur in accordance to the change of the progressive age[10] and the variability in the rate of human development is multifactorial. Skeletal development is generally assessed by examining growth in height, analysis of centres of ossification, changes in bone anatomy and fusion of epiphyses of various skeletal structures.[5] On the one hand, conditions such as chronic disease, malnutrition, hypothyroidism, constitutional delay, and growth hormone deficiency, delay the onset of puberty. On the other hand, there are conditions that accelerate skeletal maturation, such as peripheral precocious puberty obesity and Marfan syndrome[29] which is an autosomal dominant heritable disorder of connective

tissue.[30] Dental development is assessed through development and eruption of all teeth.[31] and the third molar is the only parameter of tooth maturation until a later age.[32]

Some studies claim that dental development shows less variability than other developmental features[5, 31] and proved to have a substantial biological stability from extreme nutritional conditions.[33] The close genetic control of dental development could be a reason.[34] Although data combining the use of bone and dentition maturation are available, there is yet a difficulty to gather a range of studies investigating the different methods that statistically are suitable as age estimators.[35]

The trilogy II: biologic factors of race, sex and genetics.

A study on American sample reported no racial difference in various stages of pubertal development between black boys and white boys but black girls were consistently more advanced than white girls.[36,37] As an example, differences of 11 months were found between bone and chronological age in African and Asian adolescents [38] Bone age using the standards of Greulich and Pyle must be done with reservations particularly in black and Hispanic girls and in Asian and Hispanic boys in late childhood and adolescence. Bone age may exceed chronological age by 9 months to 11 months 15 days.[39] It can be argued that the concept of race is controversial because throughout the centuries, many regional populations have been largely formed by massive immigration from different parts of the world. In multi-ethnic regional populations, races are simply ethnic groups linked to stereotypical ideal phenotypes.[40]

Over the past decade, international scientists have been gathering efforts to systematically “map” human variability focusing mainly on genetic variation.[41] Genetic predisposition is a major element of linear growth, however, favourable environmental conditions are needed in order to genetic potentials be fully expressed.[42] Studies showed that genetic transmissibility ranged from 41% to 71% in the average difference in height between monozygotic twins is only 2.8 cm, contrasted to 12 cm for dizygotic twins of the same sex.[37]

The trilogy III: nutrition, environmental factors and pathology.

Specific nutrient intake is other determinant of growth and it has a significant modulating effect on the timing of sexual development.[37] Malnutrition causes growth impairment and it is observed in developing countries and marginal individuals from cities of developed countries. [43] Obesity is a factor that accelerates the human development as an increase in body mass index (BMI) percentile is considered to be linked with an increase in both skeletal and dental development.[44]

The country of residence should be taken into consideration when discrepancy in bone age is discussed due to factors such as antenatal issues, general health, nutrition, climate, or vitamin D and calcium levels.[38] People from the same ethnic origin can develop differently when living in different countries. Environmental influences, for instance, manifest in patterns of socioeconomic variation within populations and changes accompany migration or ecological conditions such as extreme temperatures, aridity and high altitudes.[43]

Pathological factors capable of altering the bone development include nocturnal enuresis, GH (growth hormone) deficit, and the practice of competitive sports, skeletal malformations and even the effects of physical agents, such as cold.[45]

Concern about Radiation Exposure

There is a general radiation safety principle named ALARA, which is an acronym for As Low As Reasonably Achievable. This principle must be employed in all reasonable methods for the sake of minimum ionizing radiation (IR) doses due to biological effects on living tissues. For reasons of safety, it is claimed that the use of radiography for age assessment as opposed to medical purposes is unethical and potentially unlawful.[10] Nevertheless, some attenuating measures could be employed to reduce the dose, for instance: the use of faster films, to reduce the exposure time, electronically-controlled timers, to produce an optimum dose, and computers and digital imaging technology.[46] It can also be argued that the human body is affected by IR coming from cosmogenic and terrestrial sources, on daily basis[47] and the society should not be so alarmed by the use of radiographs, either for diagnostic or investigative purposes. Understandably, the type and the number of radiographs should be taken into consideration.

Dental Age assessment in late adolescents and reliance on third molars development.

Changes in dental development are frequently studied in order to estimate age. Research has shown that chronological age is more highly correlated with dental age than any of the other biological variables.[48] Dental development is less influenced by environmental circumstances than other maturation parameters.[45] Those characteristics make teeth development a reliable parameter for age prediction.

The primary dentition begins to develop before birth and starts to erupt into the mouth of a baby at 6 months[49] followed by the permanent dentition. This is completed with the eruption of the third molar at the age of 17–21 years.[50] It is assumed that the best accuracy for dental age estimation is reached when individual has many teeth under development, which is chronologically up to the age of 14 years. After that, the analysis is dependable solely on molars, particularly, the third molars.

In late adolescence, the main criteria applied for tooth age prediction are the eruption and mineralization stages of the second and third molars.[51] Some research claim that a simple dental examination would avoid the exposure of young people to the radiation [10], however, very often an OPG is required for the analysis of root development. In particular, third molar maturation has been extensively investigated in a wide range of population[52] and a few concerns should be considered such as: (a) it is the tooth with the highest variability of timing of development[32] (b) is morphologically most variable with a variety of crown and root anatomy and also (c) is the tooth with the highest level of agenesis and the prevalence of agenesis varies in the population studied.[53]

The eruption of the third molars is a variable physiological phenomenon with a high degree of variability, therefore, it is more appropriate to evaluate its development, which is more stable.[45] There are some negative aspects of the third molars, for instance, they are congenitally absent in up to 10% of population and the methods of age assessment vary between countries with present standard deviations of at least 2 years. As an example, studies on third molar development in different ethnic groups showed that the third molar in

black South Africans mature on average 1–2 years earlier than in Germans and 3– 4 years earlier than in Japanese populations.[24]

More food for thought

Maturity indicators are not exactly the same as the progress of chronological age, because the temporal landmarks can be variable and inconsistent during the transit of the individual from an immature to mature state.[54] More importantly, maturity, as an instrument to aid chronological age, has a best precision of ± 2 years. This possible degree of 4 years of variation should be taken into consideration when estimating age with regard to immigration status or criminal responsibility. [54, 55] This is particularly problematic to the threshold between the legal ages of 16, 17, 18 and 21.

Regarding the age assessment of asylum seekers, the professionals that apply age estimation methodologies should analyse: A) the background of asylum seeker children. They are psychologically vulnerable and they migrate under unfortunate circumstances such as war or poverty. Most asylum seekers come from poor developing countries where patterns of maturation might differ, as well as, differences attributed to genetics and nutritional status.[21] B) most study samples in age estimation research are not from this kind of population as, normally, the researcher only has access to individuals of his/her own country. Without an understanding of the population differences or similarities and the effect of various factors on growth of maturity indicators, these reference data to estimate age should be interpreted with caution. Often, bone and dental age estimation literature is disconnected from the statistical literature which normally provides the basis for rationale analyses.[56] It is also difficult to prove that an individual under age assessment is not an outlier. For instance, analysis of third molar was shown to have high specificity and positive predictive value but low sensitivity, negative predictive value and accuracy.[21]

Finally, suggested requirements for a valid age indicator are the following: 1) the characteristic employed displays progressive and unidirectional change with age; 2) it should be possible to categorise and measure the morphological changes and the results must have low observer errors; 3) the morphological changes should occur roughly at the same time in all people with possible

divisions for sex and ancestry; [21] 4) variability of maturation within the individual must be considered; 5) there is a clear sexual dimorphism within human growth and maturation as females tend to be advanced relative to males.[54]

Conclusion

A multidisciplinary approach is recommended for the legal age assessment due to the seriousness of the outcomes and finally, the experts should recognize the reality that chronological age will not always follow the maturity parameters of human development. Current requirements should become mandatory and updated when necessary.

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